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Comparing the use of small sized electric vehicles with diesel vans on city logistics

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Abstract

Many actions have been recently carried out within European cities with the aim of reducing the negative impacts on traffic and environment caused by city logistics. Promising results have been reported with the increasingly popular initiative of the use of small sized electric vehicles (SEV), due to their improved energy efficiency, local zero emissions and lower traffic disturbance. Along this paper, on a first step, the authors estimate the effects of adopting SEV from the city perspective. Therefore, authors analyze how the use of small sized electric vehicles such as tricycles and cargo cycles in city logistics affects traffic, energy efficiency and emissions. First, the authors identify what should be the geographical coverage of implementation of small sized electric vehicles solutions. Second, authors identify the market penetration share by small sized electric vehicles that lead to better results in terms of traffic, energy and environment to all stakeholders directly affected by city logistics operations. The assessment follows two distinct approaches, based on geographical coverage and on stakeholders' impacts. The first one distinguishes the impacts of the initiative at street level, unit level and on the city system. Such analysis reflects the behaviour of the all spatial system and allows having a broader view on the geographical impact of the initiative. The second one distinguishes the respective impacts disaggregated by stakeholder group. It will be presented the environmental, operational and economic effects of 4 scenarios of market penetration by small sized vehicles, replacing diesel vans on city logistics by 10, 30, 50 and 100%. The results show that the geographical scale that leads to better energy, environmental and traffic benefits is the street level, acknowledging the short distance scope of SEV's. At this geographical coverage, SEV lead to better improvements on the motorized mobility of the area, when the scenario represents a market penetration by 10%, with a reduction of delays by 10%, distance travelled by 16% and speed by 7%. On a second step, authors estimate the effects of adopting SEV from the suppliers (industry) perspective, focusing on operational costs and determining the break-even point under the conditions previously defined. The methodology is applied to Porto (Portugal) and calibrated with real world on-road performance of SEV on different driving conditions. In the 10% scenario the WTW energy consumption and CO₂ emissions are reduced by 3 to 4%. Also for this scenario, 56 euros per year must be spent to save 1 MJ of energy in WTW, which does not proves the use of SEV's on city logistics as particularly effective.

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1. Introduction

The increasing urbanization, population growth and the changes on the demand patterns, favouring just in time solutions, added to the reduced stock in stores, has led to increasing freight movements. The increase in freight movements has been followed by a decrease on the freight and passenger mobility on transportation systems due to the lack of associated increases in capacity. As a result, despite the relevant role of urban goods distribution in the sustainable development of cities, freight movements have also been related with negative impacts on the economic power, accessibility, quality of life and on the attractiveness of urban areas. The most common examples are mainly the impact on traffic congestion of commercial vehicles, as well as of the road capacity reduction caused by frequent stops for loading or unloading operations, and of resulting lower fuel efficiency and higher emissions (Russo and Comi, 2012; Giuliano, O'Brien, Dablanc, & Holliday, 2013).

Under such context, society is putting public administrators' a difficult challenge, which cannot be delayed anymore. Public administrators must maintain and promote their sustainability, mobility and quality of life, while ensuring that urban goods distribution systems efficiently serve their city's needs. As a result, public administrators want to promote urban goods distribution solutions that are environmental friendly and, at the same time, efficient enough to satisfy, both society and distribution companies (Melo, 2011). Various measures and initiatives have been recently promoted with this goal, namely the introduction of small size electric vehicles (SEV) approached on this paper.

A SEV is a vehicle with smaller dimensions than conventional commercial vehicles, powered by an electric motor instead of a conventional internal combustion engine. In terms of operational costs, SEV offer benefits over larger conventional diesel vans and trucks on taxes, insurance, storage and depreciation costs. In terms of operations, SEV are easier to park than vans or trucks and are viewed as less intimidating and safer by the public (Browne, Allen, & Leonardi, 2011). In addition, SEV allow the reduction of the total kerbside space occupied by vehicles making on-street deliveries, further reducing the impact of unloading operations on traffic congestion. SEV also presents social and environmental advantages that can include noise reductions, less conflicts with other road users and greater pedestrian safety.

In spite these benefits for society, SEV still need to overcome some obstacles to guarantee its acceptance by private stakeholders. Their acceptance will be influenced by the acknowledgement of SEV impacts on their operational and acquisition costs. On that, SEV's might find some reluctance by suppliers on what concerns these vehicles limitation in terms of weight and volume and in terms of the distance they can realistically be used to deliver over, due to their autonomy restrictions. Furthermore, despite it seem reasonable that local administrators should bring to discussion the industry stakeholders, most of the times private interests are overlooked. It is still assumed that suppliers will adapt their operations to the new regulations and conditions imposed by the city to city logistics operations.

Along this paper, authors will consider public interests, commonly related with quality of life, mobility and environmental issues. Simultaneously, it will consider private interests often related to turnover levels like customer levels, costs levels (operation and driving), service levels, and efficiency. In order to make all interests transparency and quantifiable in terms of impacts, a simulation exercise will be carried out as a tool to evaluate possible scenarios and choose the ones that will lead to better overall benefits. Thus, authors will simulate alternative scenarios in terms of traffic, environment and energy consumption so that it estimates the effects, both for public and private interests. The traffic and environmental impacts before and during the introduction of SEV are estimated, for different market penetration scenarios and different geographical scales. These results allow understanding the effects of replacing vans by SEV on city logistics, namely in the definition of what should be the geographical coverage for the use of SEV's within the city, its significance in terms of market penetration that maximizes the benefits of all the interests involved, and the comparison of its energy efficiency, resulting emissions and operational costs with the ones of larger diesel vans.

2. State of the art

City logistics takes place in areas with high density of buildings and population and a high demand for goods and services. Added to the current urbanization levels, important phenomena and transformations on the market like the internationalization and globalization of the economy, fast changes on markets and high pressure to reduce costs and to improve the type and level of service to customers contribute to a higher number of movements of goods and services to urban areas. Thus, such context is currently being followed by an intense pressure to reduce emissions and congestion associated with commercial movements.

Towards this local and global emission reduction goals as well as motivated by the predictable reduction of oil resources, research and industry have started to investigate solutions for the electrification of commercial vehicles, namely, heavy duty vehicles (Birkner, 2012). The electrification of commercial vehicles could reduce emissions and thus, contribute to a better quality of life in cities aimed by public stakeholders. However, the use of electric trucks still raises some apprehension on suppliers about its operational competitiveness (running and purchase costs, vehicle performance) in comparison with diesel conventional ones. The running costs directly influenced by the price of electricity are predictably competitive. Electricity presents lower and more stable prices in comparison to fuel fossil energy sources volatility and it is unlikely that electricity price increases due to this EV phenomenon. Moreover, the current scarcity and slow penetration rate of EVs ensures that the effects of EV can be anticipated by public electric companies and, therefore, the supply of electricity is not a constraint to the deployment of electric trucks (Davis and Figliozzi, 2013). The running costs of electric cars are actually lower, but these do not stand out sufficiently on a total cost basis (Thiel et al., 2010). The purchase costs of electric trucks are still high and can negatively influence its operational competitiveness. Some authors point as the major obstacle to rapid market penetration at the moment, the higher initial investment required when compared to conventional combustion engine vehicles (Kley et al., 2011). Reports on ELCIDIS (Electric Vehicle City Distribution) successful project commissioned by the European Union, identify the high purchase cost of electric vehicles as the substantial obstacle to widespread implementation of electric trucks (Vermie, 2002; vanRooijen and Quak 2010). A similar mention is made by Feng and Figliozzi (2012) when concluding that electric trucks are only competitive if EV purchases prices fall at least 30% and if its utilization level is high.

Despite the growing interest in EV technology and the fact that electric trucks can indeed contribute to mitigate the environmental impacts of city logistics, they are not more effective in reducing traffic disturbance caused by commercial vehicles during unloading operations. Their size is similar and consequently, so is their respective disturbance. Alternatively, the downsizing of vehicles without “penalty costs” of unsatisfied demand, using small size electric vehicles (SEV), such as electric cargo cycles and tricycles replies to environmental and security concerns over transportation energy use (Bartern, et al., 2012). One possible alternative to overcome this issue is the use of. The reason behind the Recent studies proved that reducing the fleet size by 10% could improve the profitability of the transportation company by 32.5% (Žak, Redmer, & Sawicki, 2011).

Considering that more than 80% of the urban freight movements are of distances below 80 km in European urban areas, (Ruesch and Petz, 2008) the use of SEV for city logistics operations can be a feasible option in operational terms. In Paris, 272 kilometres of bicycle lanes were recently created, making it possible for 30 electric tricycles “*Petite Reine*” to enhance the productivity of delivery operations, running from a consolidation centre with 600 m² and saving 660 000 km of diesel vehicle. London carried out a similar trial experiment between 2009 and 2010 and resulting in the test of 6 cycles, 3 electric vans, one truck and total savings of 62% CO₂ (kg/parcel). Brussels presents the example of Ecopostale, using 4 bicycles, 7 cycles and one electric van, reaching saving of 13 tonnes of CO₂. Barcelona estimated savings of 912 kg CO₂ / year/trike with the implementation of such system. In the City of London, replacing diesel vans by electric vans and tricycles operating from a micro-consolidation centre, indicate that the total distance travelled and the CO₂ eq emissions for parcel delivered fell by 20% and 54%, respectively (Browne, Allen, & Leonardi, 2011).

Along the case study presented on the following section, authors estimate the effects of downsizing city logistics vehicles without penalty costs of unsatisfied demand. It is analysed the effect of replacing vans on city logistics by SEV's, considering public and private stakeholders' interests, in the city of Porto. Considerable

changes on the distance travelled, energy consumption and CO₂ emissions as well as on running costs are also discussed.

3. Case study

This paper analyses how the use of small sized electric vehicles, replacing or working as a complement of vans and trucks in city logistics movements and operations, affects traffic, energy efficiency and emissions. The analysis is based on the comparison of 4 scenarios applied in the city of Porto, which present an estimation of the traffic, environmental, operational and economic effects of a market penetration by small sized vehicles on city logistics of 10, 30, 50 and 100%. The assessment follows two distinct approaches, based on geographical coverage and on stakeholders' impacts. The first one distinguishes the impacts of the SEV's at street level, unit level and on the overall system (city). Such analysis reflects the behavior of the all spatial system and allows having a broader view on the geographical coverage of the initiative. The second one distinguishes the respective impacts disaggregated by stakeholder group. The analysis of the stakeholders effects will be carried out through the quantification of indicators by type of vehicle on the SEV, vans, trucks (transporters/suppliers), on passenger's vehicles (citizens and city users), on buses and taxis (public transport operators) and on the total system (motorized society). The following indicators were quantified: distance travelled, energy intensity (fuel consumption) and global CO₂ in a fuel life-cycle approach (Well-to-Wheel), average speed (excluding stops to make deliveries), travel time, delay time, density of traffic. The Well-to-Wheel approach includes both the Tank-to-Wheel (TTW), regarding the fuel/energy usage at the vehicle, and the Well-to-Tank, regarding the energy spent to bring and produce the fuel/energy vector from its source to the user.

3.1. Overview of the area

The case study was carried out in the city of Porto (Portugal), using the delivery patterns information collected with windshield surveys. Three geographical levels of study were chosen: street, unit and city. Figure 1 illustrates those areas.

The streets marked in blue represent areas with significant traffic disturbance due to city logistics operations. Considering the homogeneity of activities, landscape and, commercial activities, three green 'units' of study were defined. Unit 1 represents Porto downtown. Unit 2 is an area with residential and commercial mixed uses and Unit 3 is an area of services. The area inside the first ring (VCI roadway) is the 'City'.

The case study analyses the impact of introducing SEV's at city level, unit level (Unit 2) and street level (the main commercial street of Unit 2: Costa Cabral Street). Unit 2 comprises 12 blocks.

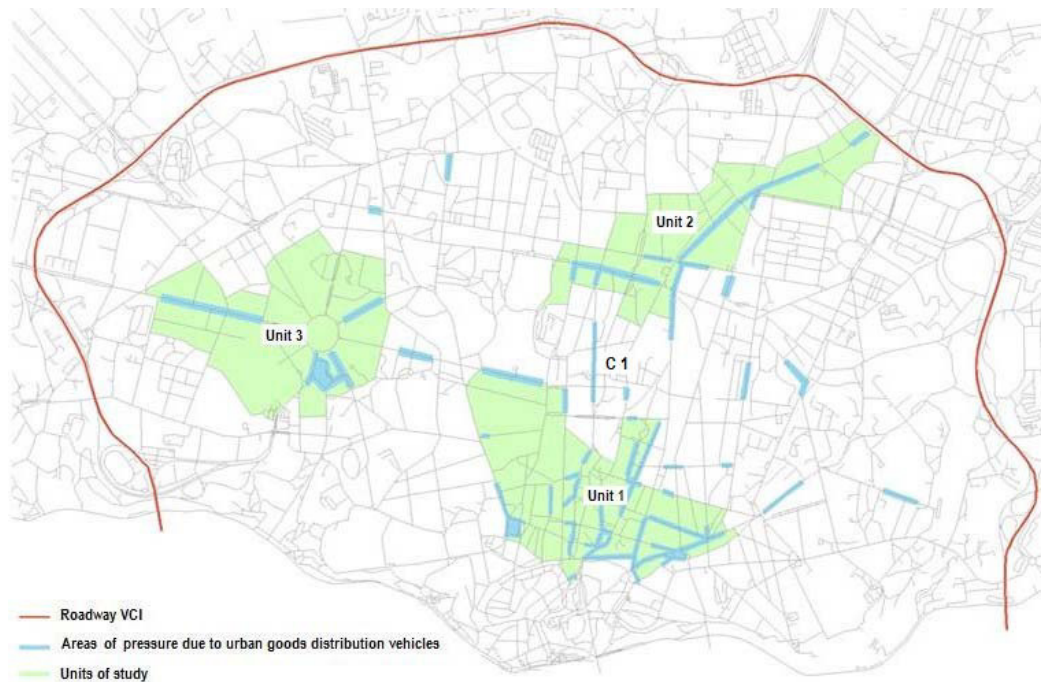


Figure 1. Illustration of the geographical areas of analysis

3.2. Estimating the impacts on traffic and environment

The 4 scenarios test the possibility of carrying out the delivery of goods using small sized electric vehicles (SEV), replacing vans by 10, 30, 50 and 100% (transport and deliver operations). The estimation of traffic impacts was carried out using AIMSUN, through specific adaptations to include SEV.

For the purpose of designing the network, 231 intersections and 559 sections were defined, respective geometry and movements, which were later confirmed in detail in loco. The simulation exercise assumed the scenarios cover the daily peak of deliveries. The traffic model assumes that the traffic demand for public, passenger and freight transport remains the same of the BAU scenario. Due to the fact that trucks are targeted for different demands of the ones of SEV, namely on the geographical coverage, type and size of packages, location of receivers on peri-urban areas, trucks demand remains the same on the O/D traffic matrix along the 4 scenarios. SEV replaces vans moving goods and thus, the sum of both O/D traffic matrices (vans and SEV's) for each of the 4 scenarios corresponds to the values of the O/D vans traffic matrix of the BAU scenario.

Seven types of vehicles were considered on the analysis according with the following categorization: SEV, car, bus, truck, van, taxi and other public transport. The vans have external dimensions of 5 m long and 2 m wide. Trucks have external dimensions of 7.5 m long and 2.3 m wide. SEVs have external dimensions of 2 m long and 1 m wide. The empty weight of the SEV is 400 kg, including the two batteries (without the driver and load weight). It has a load space of 1 m³. It has an average speed of 30 km/h in free flow conditions. Roughly 90% of the stores receive a single parcel. At some stops, the driver makes deliveries to more than one store due to their close proximity to one another. The range of parcel sizes and weights makes it viable for all parcels to be delivered by SEV. The SEV requires 8 hour recharging overnight. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during delivery windshield surveys. Incidents representing illegal parking on the road were defined in a detailed way. Section where incidents occur,

position on the lane and length of the event were defined according with real data obtained on windshield surveys. On the BAU scenario, incidents were mostly caused by vans rather than trucks. Vans incidents were replaced by SEV incidents on the proportion of each of the 4 scenarios: 10, 30, 50 and 100%. Outputs of the simulation exercise refer to the hourly average of the peak period.

3.3. Geographical coverage and market penetration of SEV

The impacts of the 4 scenarios were compared in order to choose the one which would bring more benefits to the study area and better predict stakeholders' perspectives and effects towards SEV. Such estimation makes the different stakeholders interests more transparent and thus, optimizes the process of decision making.

Table 1 presents the estimated effects of four scenarios of market penetration of SEV (10, 30, 50 and 100% introduction) at the city level.

These results are consistent with worst traffic conditions and worst mobility. If SEV's would move and deliver goods, replacing 10%, 30%, 50% or 100% vans, the results would be negative in terms of traffic, since the density and delay times increase. The speed decreases leading to a lower distance travelled and higher travel times. Table 1 shows that SEV's with a market share equal or greater than 10% should not be used at the city level.

Table 1. Effects of small sized electric vehicles on city logistics at the city level compared to the BAU scenario

Market Penetration Scenario	Travel Time (seconds)	Delay Time (seconds)	Speed (km/h)	Distance Travelled (km)
10 % SEV	8%	9%	-2%	-7%
30% SEV	8%	9%	-4%	-12%
50% SEV	26%	29%	-6%	-4%
100% SEV	19%	20%	-9%	-4%

Table 2 illustrates the effects of the same 4 scenarios at Unit 2 geographical scale in comparison with the BAU scenario.

Table 2. Effects of small sized electric vehicles on city logistics at the unit level compared to the BAU scenario

Market Penetration Scenario	Density (Veh/km)	Travel Time (seconds)	Delay Time (seconds)	Speed (km/h)	Distance Travelled (km)
10 % SEV	2%	1%	3%	0%	-5%
30% SEV	4%	1%	2%	0%	-12%
50% SEV	2%	4%	6%	0%	-9%
100% SEV	4%	1%	0%	-1%	-6%

Similarly, at this scale, the results are negative, independently of the simulated market penetration shares. However, at the unit level, there is a lower relative and absolute traffic effects resulting from the adoption of SEV along the 4 scenarios. The average speed remains the same at 33 km/h. Other indicators reveal minor changes that are consistent with a slightly higher congestion levels. Density of vehicles, travel time and delay time slightly increase, and the distance travelled slightly decreases. In absolute terms, these changes are minor, and thus, despite the consistent tendency of worst mobility in all scenarios, these results demand some caution on its

interpretation. Unit 2 includes 12 blocks, thus it is still a large area to be covered by an SEV, considering their limitations in terms of weight and distance travelled. This means that SEV with a market share equal or greater than 10% should not be used at the unit level, with such area coverage.

Table 3 illustrates the traffic effects at the street level. The variation of the effects in each of the scenarios requires some caution on its interpretation. Changes on the mobility of the street can be explained with the intrinsic characteristics of the SEV and with the partial removal of vans. SEV circulate at an average speed of 28 km/h along the street and have a lower dimension than vans. Such intrinsic characteristics make it easier for other vehicles to overcome SEV rather than they would for vehicles with conventional dimensions, such as vans. This easier movement can also be observed for an SEV illegally parked during unloading operations, which creates less traffic disturbance than vans. The partial removal of vans at the street level affects their traffic state and thus, also leads to improvements on the overall network. The final results of estimations are a composed consequence of all these factors happening at the same time.

Table 3. Comparison of 4 scenarios of small sized Electric Vehicles Market Penetration for City Logistics at the street level compared to the BAU scenario

Market Penetration Scenario	Travel Time (seconds)	Delay Time (seconds)	Speed (km/h)	Distance Travelled (km)
10 % SEV	2%	2%	-5%	-14%
30% SEV	3%	7%	-8%	-17%
50% SEV	-4%	-9%	-8%	-17%
100% SEV	-8%	-11%	-15%	-17%

On the first and second scenarios, with SEV representing 10% and 30% of the vehicles moving goods within the city and delivering them at the street chosen for the case study, the speed decreases due to the presence of slower vehicles moving and delivering goods. The decrease on distance travelled is mostly caused by the decrease on speed. The travel times and delay times increase, but there is an increasing density (25%, from 64 to 80 vehicles/km on scenario 3).

On the third and fourth scenario, with SEV representing 50% and 100% of the vehicles moving goods within the city and delivering them at the street chosen for the case study, the results are positive. Changes of about -10% on delay times (to 42 seconds), travel time (to 60 seconds) and density (from 64 to 57 vehicles/km) are observed.

The area coverage of SEV should be the street level. At the previous geographical levels of analysis, SEV with a market share equal or greater than 10% would lead to worst traffic conditions. At the street level, the market penetration share can be higher than 10% as the best of the 4 scenarios is the one that estimates the effects of a market share of 50%. Further intermediate market shares between those scenarios should be analysed in order to establish more precise boundaries to SEV.

3.4. Estimating the energy, environmental and operational impacts

From the traffic condition analysis, SEV were considered beneficial at the street level, under a public objective perspective, closer to driving behaviour outputs. Along the following analysis, the result of an estimation closely focused on private objectives, targeting purchase behaviour indicators, is presented. In this context, the influence of the studied scenarios on the kilometres travelled by each vehicle technology performing the distribution of goods is presented in Table 4.

Table 4. Distribution of yearly kilometers travelled at the street level

Scenarios	Distribution of yearly kilometers travelled		
	SEV	Van	Trucks
BAU	0%	36%	64%
10 % SEV	7%	39%	54%
30% SEV	13%	33%	54%
50% SEV	27%	20%	54%
100% SEV	54%	0%	46%

The kilometres performed by SEV increase in the 4 scenarios, while the performed by conventional technologies decreases. The total kilometres travelled are not constant since they are affected by intrinsic characteristics of SEV's and with the partial removal of vans as well as the traffic conditions that result from these factors interacting simultaneously. If the delivery of goods is carried out with SEV, the unloading operation causes fewer disturbances. The movement of the SEV is slower but, as it is carried out with a smaller vehicle, it is easier to be overcome by light vehicles. These values result from the reduction of the diesel fleet being replaced by the SEV fleet. Therefore, added to the effect of having smaller vehicles unloading goods (with less disturbance), slower ones (affecting the other vehicles speed), a share of 10% of SEV's implies a reduction on the O/D matrix of Vans by 10%.

Additionally, the energy and environmental effects associated to these scenarios were estimated in a yearly timeframe. These assumed energy consumption and emissions factors are based on previous work for the Portuguese average fleet (Baptista et al. 2012). The magnitude of these impacts is directly related to the kilometres travelled, and can reach 56% and 59% reductions in WTW energy consumption and CO₂ emissions in the 100% SEV scenario.

With current policies and technology estimates, SEVs will likely be less than 10% of the fleet in 2030, as it had also been defined as the best scenario of the fourth that were tested. Therefore, the following analysis considers the scenario of 10% to the geographical coverage of the street level and this might be the most positive and suitable scenario for SEV's in the coming future. This scenario would result in 3.1 and 3.6% reductions in WTW energy consumption and CO₂ emissions. Moreover, the additional cost of deploying and running the vehicles (including fuel savings and additional driver costs) per unit of energy saved was estimated. The driving costs of diesel vans and trucks would be reduced due to the decrease on delays, representing running costs savings up to 178 euros per year. The driving costs of SEV's would however represent additional running costs of 170 euros per year along the street. Such results imply that, for the 10% SEV scenario, 56 euros per year must be spent to save 1 MJ of energy in WTW.

4. Conclusions

Despite the increasing promotion of SEV, there are still some reservations to its implementation. Operational and economic issues are supporting these reservations. One of the main issues is that SEV can only cope with parcels and not pallets and, consequently, SEV only covers specific types of business. The size and weight of parcels are rather small and the travel distance must be short. Moreover, it implies the existence and availability of a small consolidation centre – can be a massive origin of flows such as a supermarket or a post office station – from where the vehicles depart and serve a high density of clients. Added to these operational issues, there are also the considerable costs of acquisition of vehicles, the difficult maintenance, a small second-hand market, and an insufficient number of refueling facilities.

Along this paper, authors estimated the effects of SEV when replacing vans to deliver parcels at the street, unit and city level coverage. The analysis under a public objective perspective (traffic and environmental effects) revealed that the coverage extent of SEV should be as short as the street level. At this level, SEV are indeed more efficient than conventional ones (in terms of traffic). Moreover, the better scenario would be the 10% of market penetration at the city scale, which confirms the use of SEV's still as a niche of market to work as a complement to conventional ones. This conclusion is coherent with the current tendency of the use of SEV on the delivery of mail and other home delivery journeys. In terms of environment, it was shown that, for the more beneficial scenario in terms of global traffic (Scenario 10% SEV), approximately 3 to 4% gains in WTW energy consumption and CO₂ emissions are obtained.

The positive results of SEV under a public perspective objective are overshadowed when the private objectives targeting operational costs are considered. Regarding driving costs, the impacts of the 10% SEV scenario are of additional costs by 170 euros/year along the street. Authors of this paper estimated that when considering only the fuel costs, the difference of operational costs is 90% lower for SEV. Despite the significance of these values, the limited payback period of consumers (i.e. the time over which fuel savings need to recover the higher alternative vehicle purchase cost) is also an obstacle to the use of SEVs. Such results indicate that SEV are not yet fully satisfactory for urban deliveries. Moreover, due to the initial stage of experiments with electric cargo cycles and trikes, there are still some cautions from suppliers, which can only be diminished through risk sharing with public stakeholders and subsidizing policies. The question is whether cities should compel themselves to actively developing this specific solution, as it is uncertain to spend a significant amount of time and money for such limited positive effects. However, if suppliers will demand it, cities should encourage the development of SEV, creating the facilities to support it.

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